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A Case Study: Teaching Engineering Concepts in Science

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1/31/2010

Abstract

This study was conducted to describe a teacher developed high school engineering course, to identify teaching strategies used in the process of delivering math and science literacy through this course, to identify challenges and constraints that occurred during its development and delivery, and to describe the strategies that were used to overcome those obstacles.

A case study was conducted using semi-structured interviews with the engineering instructor at Benilde-St. Margaret's in St. Louis Park, Minnesota. In addition, the researcher conducted classroom observations and reviewed instructional materials, teacher lesson plans, and teacher journals.

Themes that developed regarding the strategies used to deliver this particular course identified that concepts created its platform for delivery, curricular trial and error was at work, science and engineering competitions were leveraged as a basis for learning activities, project based learning and teaching were employed, there was a clear emphasis on creative thought and work, and the teacher served as a guide rather than the sole "sage".

Themes developed regarding the identification of challenges and constraints that occurred during the development and delivery of this engineering course were assessment of student learning was dubious and elusive and stakeholders tended to be uneasy with this new pedagogy. Lastly, themes developed regarding the strategies used to overcome these obstacles identified financial and instructional support through business partnership and administrative support as being critical.

Introduction

The focus on improving science, technology, engineering, and mathematics (STEM) education for America's children can be traced back to the 1957 launch of Sputnik and beyond. However, compared with advancements then, it has been argued that technological development and industrial growth are now increasing at an exponential rate with expanding global application (Brophy, Klein, Portsmore, Rogers, 2008). Indeed, driven by the rapid development of enabling technologies, industries must become much more flexible and adaptive to remain competitive. Consequently, amid concerns that the United States may not be able to compete with other nations in the future due to insufficient investment today in science and technology research and STEM education, funding initiatives as the American Recovery and Reinvestment Act (U.S. Department of Education, The American Recovery and Reinvestment Act of 2009: Saving and Creating Jobs and Reforming Education) and "Race to the Top" competitive grants have been enacted in 2009 in effort to offer substantial federal support for such initiatives (U.S. Department of Education. President Obama, U.S. Secretary of Education Duncan Announce National Competition to Advance School Reform). The support structure for STEM education does not end with tax dollars. Large private companies such as Time Warner Cable committed $100 million in media time and the MacArthur Foundation is supporting "National Lab Day" that will include, among other initiatives, a year-long effort to expand hands-on learning methods throughout the country.

Specifically, within the STEM focus, engineering education supports the attainment of a wide range of knowledge and skills associated with comprehending and using STEM knowledge to achieve real world problem solving through design, troubleshooting, and analysis activities (Brophy, et. al., 2008). The arguments for including engineering education into the general education curriculum are well established. Some are motivated by concerns regarding the

quantity, quality, and diversity of future engineering talent (American Society for Engineering Education, 1987; National Academy of Engineering, 2005; National Research Council, 1996; International Technology Education Association, 2002) and others by the basic need for all students, in their pursuit of preparing for life, work, and citizenship in a society inundated with technology, to possess a fundamental understanding of the nature of engineering (Welty, 2008).

In an attempt to address this issue, there have been a number of curricula designed to infuse engineering content into technology education courses (Dearing & Daugherty, 2004). Each of these programs proposes teaching engineering concepts or engineering design in technology education as a vehicle to address the standards for technological literacy (International Technology Education Association, 2000/2002). Similarly, the National Academy of Engineering (NAE) publication *Technically Speaking* (Pearson and Young, 2002) emphasizes the need for all people to obtain technological literacy to function in the modern world. However, despite this clear need, within the technology education profession itself, the appropriate engineering curriculum required for implementation, particularly at the high school level, remains unclear. Indeed, engineering curricula have been designed for implemetation, not in technology education, but in math and science classrooms also exist. As a result of the choices available to teachers and school administrators, the extent to which the most effective way of delivereing engineering content to high school students is remains unclear.

Problem Statement

Since there is a lack of consensus on how best to deliver engineering experiences to high school students, there is a need to identify attributes of programs that have been successful in doing so. As a result, this study was designed to examine such a high school engineering course taught by Tim Jump of Benilde-St. Margaret's, a Catholic college preparatory school for students in grades 7-12 in St. Louis Park, Minnesota. While *Advanced Competitive Science* is the official title of this elective course in grades 10-12, the term, "engineering education," will be used in this report. This case study examined the attributes of this highly regarded secondary school course because of its organic approach to curriculum development and unique focus on engineering concepts borne of the motivation to reinforce math and science concepts.

Research Questions

Five semi-structured interviews were conducted with the instructor of the high school engineering program previously mentioned in order to identify ways of successfully delivering engineering content at the high school level. In addition, classroom observations were made and curriculum documents and teacher lesson plans were gathered and examined. The results will focus on that part of the research which proposed to:

(a) describe high school engineering curriculum developed with the sole purpose of delivering math and science literacy;
(b) identify teaching strategies used at the high school level in the process of delivering math and science literacy in the context of an engineering program;
(c) identify challenges and constraints that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts; and
(d) strategies used to overcome these obstacles.

A pre-interview with the instructor was also conducted to determine what he considered to be relevant data to collect in order to capture the experiences. As a result, the following questions were used to guide the interviews:

1. Why have you chosen to implement engineering into a high school science program?
2. What changes have you had to make to your science curriculum to teach engineering concepts?
3. What new strategies have been generated in order to successfully implement engineering curriculum?
4. What curriculum resources have been most helpful to you in order to make this change?
5. What equipment, tools, and software have been added to your classroom for the purpose of effectively delivering engineering concepts?
6. What challenges or constraints have you faced when seeking to implement engineering concepts into your classroom?
8. How have you overcome those identified challenges/constraints?
9. What advice would you give a technology teacher who seeks to implement an engineering course?

Literature Review

The arguments for including engineering education into the general education curriculum are well established and it has been suggested that technology education align itself with engineering for a number of reasons: to gain acceptance by academic subjects; serve as an invitation to the engineering community to collaborate in the schools; increase the social status of technology education; and ease the justification of the subject in schools' communities (Bensen & Bensen, 1993). Other leaders in the field of technology education, as well as the engineering education community have also identified the role K-12 engineering education plays in the success of postsecondary engineering education (Douglas, Iversen, & Kalyandurg, 2004; Hailey, Erekson, Becker, & Thomas, 2005). However, with the multiple curricular shifts made prior to this point accompanied by its vocational and hobbyist leanings emanating from its past, this will be no easy feat for technology education (Lewis, 1995). Considering these issues, Wicklein (2006) proposed that if the technology education curriculum is organized around engineering design, the goals of technological literacy and creating a well defined and respected framework of study that is understood and appreciated by all can be accomplished.

However, even from within the profession itself, the appropriate engineering design content required for implementation into high school technology programs remains unclear. In attempt to address this issue, there have been a number of curricula designed to infuse engineering content into technology education courses such as Project ProBase, Principles of Engineering; Project Lead the Way, Principles of Technology; Engineering Technology; and Introduction to Engineering (Dearing & Daugherty, 2004). Each of these programs proposes teaching engineering concepts or engineering design in technology education as a vehicle to address the standards for technological literacy (International Technology Education Association, 2000/2002).

It has been argued, however, with math and science already well established in the curriculum, engineering, with its heavy reliance on both of these subjects, may be redundant (Lewis, 2007). Even though Lewis goes on to explain that the math and science curricula may

not be able to produce authentic representations of engineering that aptly capture the ill-defined and creative nature of this type of work, the idea of science and math having a significant stake in K-12 engineering education is worthy of inquiry. Indeed, to educators, curriculum designers, and educational researchers, the benefits of significant engineering related activities such as design, trouble shooting, and reverse engineering, are well known and serve as popular instructional models in science, math, and technology in order to meet many of their standards (Brophy, et. al., 2008). In fact, the National Science Education Standards emphasize the importance of how design and understanding of technology inform students' understanding of science (National Research Council, 1996). Also, the National Mathematics Standards (National Council of Teachers of Mathematics, 2000), who have been viewed as a complement to science standards, aim to develop competencies (a fluent and flexible sense for numbers, mathematical operations and representations to perform analyses as a part of problem solving, and estimate mathematical calculations rather than relying on paper and pencil procedures just to name a few) that are integral to and can be uniquely addressed by engineering and design curricula. In fact, curricula such as The Infinity Project, Learning By Design, Models and Designs, and A World in Motion were developed chiefly to promote understanding of math and science concepts by employing engineering design activities, not solely to promote technological literacy in technology education courses (Welty, 2008). Very little research has been conducted with regard to how particular engineering education experiences differ from mainstream science and math instruction (Brophy, et.al, 2008). How do high school programs designed to specifically increase science and math literacy rather than technological literacy approach engineering design curriculum? Said differently, when many of the engineering curricula is designed to be infused in an existing technology education program, how do high school engineering education programs derived organically from a science and math emphasis approach engineering design curriculum? In essence, can there be a distinction made between different "learning environments" in the sense of intellectual outcomes targeted (technological literacy vs. science and math literacy) by the subject being taught?

  The curriculum products mentioned above (specifically, Project ProBase, Principles of Engineering; Project Lead the Way, Principles of Technology; Engineering Technology; and Introduction to Engineering) are prescriptive in their design and approach to delivering engineering concepts to students in technology education programs. These curricula are designed to deliver this content via objectives, usually involving facets of technological literacy in the case of technology education, for the course or program of study. The source of these objectives includes what has been determined by experts that students need to know and what society deems important to teach. Once objectives have been established, a curriculum subsequently suggests the content to be taught, the methods to deliver it, and the eventual assessment of the material is recommended as well (Saylor, Alexander, and Lewis, 1981; Tyler, 1949). This deductive model of curriculum development diagrams the process of how many curricula are designed – engineering curricula being used in technology education programs, and science and math (The Infinity Project, Learning By Design, Models and Designs, and A World in Motion), included.

  However, a *descriptive* model of curriculum design takes a different approach. Walker (1971) described this type of model as being primarily descriptive which is in contrast to the classic prescriptive model described above. Coining this model as *naturalistic*, Walker explains that it entertains objectives, learning activities, and evaluation as cyclical in nature and a means

to inform the *platform* that established the basis for the curriculum. This *platform* is defined as essentially the shared beliefs or principles that guide the developers of the curriculum. This platform is developed through discussion regarding the developers' values, beliefs, perceptions, and commitments relative to the curriculum in question. This mix of positions lays groundwork for a deliberation that takes place that involves the issues with the current curriculum being used and ways to eliminate frustration with its inadequacies. After this is completed, however, the actual design of the curriculum can begin (Walker, 1971).

The organic nature of this type of curriculum design is obvious and is in contrast to the design of the curricula currently being used to infuse engineering design into technology education courses and programs, as well as in math and science classrooms.

Method

In considering research tactics for this study, the need for a method to investigate the phenomenon of engineering curriculum delivered via curriculum developed naturalistically to deliver math and science concepts in an authentic manner lends itself well to a case study strategy. It is important to note that a case study is not selected for its methodology. It is instead selected by the interest in a specific case (Farmer & Rojewski, 2001). Case studies are often used to contribute to our knowledge of individual, group, organizational, social, and related phenomenon in many situations to contribute to our knowledge of individual, group, organizational, social, political, and related phenomenon (Yin, 2003). Yin (1994) identifies that there are three main types or approaches to case studies: exploratory, explanatory, and descriptive. The type of approach taken depends upon the purpose of conducting the case study. This research study used an exploratory approach that was designed around the aforementioned research questions. Semi-structured interviews were conducted with Tim Jump, classrooms were observed, and curriculum documents and teacher lesson plans were examined in an effort to carefully develop an understanding of the complexities of this case (Creswell, 2007).

The participants for a case study were selected because they represent a specific phenomenon (Gall, Gall, & Borg, 2007). Jump served as an archetype of successfully implementing an engineering curriculum developed via the naturalistic method of curriculum design to satisfy the platform of delivering math and science concepts more effectively to high school students though engineering design activities.

After assembling data from the interviews, classroom observations, and collected curriculum documents, analysis of the data began by review of the interview transcriptions, field notes, and curriculum documents. Microsoft Word was used organize the research data for analysis via tables, meaningful groupings, and combining and synthesizing data across multiple sources (Ruona, 2005).

Data Analysis

This case study examined the attributes of this highly regarded secondary school program because of its organic approach to curriculum development and unique focus on engineering concepts borne of the motivation to reinforce math and science concepts. To that end, questions were asked in order to identify teaching strategies used to deliver math and science literacy in the context of an engineering program, describe high school engineering curriculum developed with the sole purpose of delivering math and science literacy, and identify challenges and constraints

that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts, as well as what strategies are used to overcome these obstacles. The researcher contacted the subject for the study, Tim Jump, email during September 2009. A letter explaining the study (appendix A) accompanied the email and the subject was invited and agreed to participate. He was contacted by email and scheduled for interview times at his convenience. Five interviews in all were conducted, lasting 60 minutes each. The participant was interviewed in their own classroom. Interviews were recorded with a tape recorder while the researcher took notes. Interview recordings were transcribed and examined for themes by the researcher. The researcher sent the transcripts via email to the participant to review the transcription, observe themes being identified, and clarify any information.

Participant

Timothy Jump is the developer, teacher and director of the pre-engineering program (Advanced Competitive Science) at Benilde-St. Margaret's School in St. Louis Park, MN. He received his BFA from Southern Methodist University 1983, as well as teaching certificates in mathematics and chemistry 1985. Jump also holds an art certification from The University of Dallas 1987. Mr. Jump's honors include membership in Phi Theta Kappa National Honor Society; Kappa Delta Pi Educators National Honor Society: Who's Who among America's Teachers. Additionally, he has been awarded an Ashland Golden Apple Award, 1997; BSM Teacher of the Year, 1997-98; Presidential Scholar Distinguished Teaching Award, 1999; MIT Teaching Fellowship, 1999; and an MHTA Tekne Award for Innovation in Teaching, 2005. Jump has been a guest presenter at: MIT MindFest; Singapore Science Center; University of Reading, UK; Bristol Science Center, UK; FIRST Scandinavia; Dartmouth College, Thayer School of Engineering; Tufts University, Center for Engineering Education Outreach; University of Wisconsin, Madison School of Engineering Industrial Board; Wisconsin Entrepreneurs' Conference; MHTA Conference; MISF STEM Conference; LifeScience Alley Conference and Expo; among others.

Along with personal honors, Jump's engineering teams have posted honors including a Certificate of Technological Innovation from the US Department of Commerce; Best Design for Manufacturability from the Society of Manufacturing Engineers; National Engineering Design Challenge National Champions; RoboCup Rescue Robot League US Open Champions; and a top ten finish at the RoboCup Rescue Robot League World Championships.

Jump was the founder of FIRST LEGO League in Minnesota and is a past member of the FIRST LEGO League International and Minnesota Advisory Boards. Jump is currently serving on the Minnesota P-16 Education Partnership, Science Instruction Working Group. After a short career in visual special effects, Jump has been employed in classroom practitioner for 24 years: eight in Texas and 16 in Minnesota.

Establishment of Themes

Themes emerged from the transcribed interviews through the use of coding. The participant's responses were coded through a process of horizontalization demonstrating the participants experiences (Moustakas, 1994) and categories defined by similar statements as they related to research questions (Creswell, 2007). Inter-rater reliability was established with the aid of collaboration with the interviewee. Both the researcher and the interviewee reviewed transcripts separately.

Reasearch Objective #1

Describe how high school engineering curriculum developed with the sole purpose of delivering math and science literacy.

 Theme 1: Concepts create the platform. As mentioned, Walker (1971) described a *naturalistic* model of curriculum development that entertains objectives, learning activities, and evaluation as cyclical in nature. Developed through discussion regarding the developers' values, beliefs, perceptions, and commitments, a *platform* for the curriculum is formed. This is fortified by discussions regarding the developers' values, beliefs, perceptions, and commitments relative to the curriculum in question. This mix of positions lays groundwork for a deliberation that takes place that involves the issues with the current curriculum being used and ways to eliminate frustration with its inadequacies. After this is completed, however, the actual design of the curriculum can begin (Walker, 1971). Jump noted conceptual learning was at the basis of developing the ACS curriculum.

 Jump. I must have had a dozen engineering textbooks and everything I've pulled out is all college textbook stuff. There is nothing for high schools… They really weren't talking conceptually about what's going on. Now this book (*Engineering Mechanics, Static's and Dynamics* by Bedford & Wallace, (2002) is full of math problems just like any other mechanical engineering textbook, but I thought that their explanation of the concepts was very good… I wasn't a mechanical engineer; I didn't go to engineering school. So I had to start discovering what are the concepts and how does mechanical engineering as a content area differ from physics?

 Jump. Then once they learn how to build with LEGO we start getting them to learn how to build with physics. The fact that just because you built it and now all of the parts fit together it's still twisting, it doesn't turn straight. It falls apart. What is it that you don't understand about the laws of physics? So that's where we introduce statics and dynamics. We start talking about forces in real things. So again they're still thinking I got to build a robot but now… at the same time teaching them all these science concepts that so often are taught as static elements. This is force… These are Newton's Laws... They need to know it because of an outcome they are trying to accomplish, so it draws them into the learning better. Well where is your load, where is the center of the mass? How do you start to understand about supports? So we get into that aspect of mechanical engineering where we really start to understand about centers of mass, of centers of volume, centers in terms of supports…

 The emphasis on conceptual learning of math and science content is made explicit in the program description:

  Advanced Competitive Science (ACS) is a conceptual engineering program in which students explore mechanical and electrical systems through fabrication and assemblies, design processes utilizing 3D modeling tools, and control systems incorporating sensor interfacing, data collection, motion control and embedded logic programming… develop advanced problem-solving skills and sub-level of mastery of formal teachings in science and mathematics as a result of direct application of these knowledge sets. By engaging students in the iterative process of problem formulation, abstraction, analysis, design,

prototyping, testing and evaluating, ACS expands student development beyond information concentricity and toward innovation and entrepreneurialism…. (Benilde-St. Margaret's, 2010)

In addition, Jump has created a series of modules for his first year Engineering 1 students. It is important to note the significant conceptual focus of these assignments. Appendix B features the scope and sequence taken from the ACS curriculum Jump has created for the Engineering 1 year long course. Although there are specific skill related topics in each of the modules that relate directly to the hardware and software he employs to deliver the curriculum, the essence of topics are focused on reinforcing concepts such as mathematical relationships, design, friction, force, structures, loads, mobility, mass, gravity, moments, couples, supports, simple machines, control, evaluation, prediction, problem solving, and systems.

Theme 2: Curricular trial and error. As noted, once the platform of a naturalistically formed curriculum is established, the actual design of the curriculum can begin. A popular cyclical approach to this process, involves revisiting the steps: selecting objectives; selecting and organizing content; selecting and organizing methods; and evaluation (Nicholls and Nicholls, 1981). The Nicholls' cyclic approach emphasizes that not just the content itself, but the approach to content should be a key aspect of the curriculum development process.

Jump explained that because there was no engineering curriculum at the time the ACS program was in its infancy, therefore no guidelines as to how the program should be structured or focused.

Jump. …our first semester I had 6 kids that I just kind of recruited to start [the ACS program]. Because we had no idea. There was no curriculum. There is no textbook. There is nothing. So day one is, alright, now that we have our table and chairs, what do you want to do?

Jump. if I try and do a physics class then there are all these physics standards that are already out there. If I try and do a biology class there are all these biology standards…Where is the time to really explore and experiment? It's like wow, there is nothing in engineering. There are no requirements, there's no anything. We can do whatever we want. There are more engineering competitions then anything out there. Again going back to our foundation of starting this, looking for competitions and so it all just sort of came together.

Jump. I didn't start off with a set of objectives and we're going to meet those objectives. I really didn't know where we were going with this. But I saw how the students responded. I think what was big for me, as an observer, when we were doing all these different projects and looking how the kids responded. There was a huge intellectual difference between doing Science Bowl when you're just buzzing in. What's really the need?

Jump. When we started this, it's been 12 years ago, of course "you can't change the sciences, they have to be taught this way." So we just grew it independently, which gave us a lot of freedom… and there is no accreditation for engineering courses so we don't have to deal with state requirements, no curriculum. There is nothing in stone. It really allowed us to just experiment. Try different things. Does this work? Does that work? What works well for the kids? Then as the kids were graduating, we were getting feedback from the colleges. "Oh this was

great, I knew this and none of the other kids did" or "you know we did that but that didn't help me at all." So just allowing the feedback from the kids, what's working, what's not, then we can tweak the program and start really understanding what the colleges are looking for. What are the critical skill sets when the kids are going into engineering school that pay huge dividends for them verses the things that just weren't working that way.

In addition, as mentioned above, there was a need not to change the current science offerings because of the college entrance requirements.

Jump. We knew that the colleges a lot of these kids want to go to still are looking for that very traditional science role… So it really grew independent of the sciences… But of course how we can integrate it in, I guess it's one of those things we talk about cross curricular or supporting. It's (ACS) very supportive because we go through all the physical science, the basic physics, we do vector analysis, they got to be able to resolve vectors, but then we bring in the problem solving end of it, the laboratory and the engineering side of it. So we skew it very much towards engineering. But in some ways it's almost like having your lecture and then your lab. This really is a fundamental lab based program. So that was something that we've done which a lot of schools are struggling with. How do we make this fit and how do we change our science programs?

The positive effects of bringing different curricular content together in a novel ways, such as engineering, is well established. Indeed, the idea of integrated curriculum has been popular because of its potential to prevent students' fragmented view of the curriculum as a more holistic approach to content. This type of curriculum aims to develop student understandings through continuous interaction, conversation, and discussion (Pidgon & Woolley, 1992). The goal of an integrated curriculum approach is to extend and refine students' developing knowledge (Murdoch & Hornsby, 1997).

One model used to plan integrated curricula is termed "threading". Threads for helping students make connections between various content areas relate to four main "ways of working". These include cooperating and interacting, reasoning and reflecting, imaging and inquiring, and assessing and evaluating (Murdoch and Hornsby, 1997, pp. 14-15).

Research Objective #2
Identify teaching strategies used at the high school level in the process of delivering math and science literacy in the context of an engineering program

Theme 1: Science/engineering competitions were leveraged. One of the most common approaches to training engineering students to think creatively is presenting them with complex, open ended design problems that are often couched in competitions. These types of problems are designed to represent "real" scenarios or issues and have many possible solutions (Lewis, 2004). The curriculum Roth (1996) identified in his study to understand the process of designing, Engineering for Children: Structures (EFCS), provides such an experience for students to construct engineering knowledge in the realm of structures. However, Roth is careful in pointing out that these activities, whose core goal is to have students construct bridges as part of an ongoing engineering competition for constructing a link between two sections of a city, are not designed specifically to "transmit legitimated and canonical engineering knowledge" (p. 130).

Rather, like the motivation for posing open ended problems generally, these activities provide students with opportunities to explore issues critical to designing, learn to manage the complexity of open ended design challenges, and gain knowledge of how to work with the group dynamics inherent in ill-structures design situations.

Jump chose to focus on competitions because of the appeal they had with his physical science students early on. However, it became evident that opportunities to engage in these same types of challenges in the areas of biology and chemistry were limited to science fairs. These required long term, isolated research projects which facilitated the need for each student to have not only the dedicated space for their work, but consistent accessibility to laboratory facilities in order to perform data collection, maintenance, trouble shoot, feed/care for animals or plants, etc. The National Engineering Design Challenge became an attractive curriculum target because of its ability to focus design and engineering thinking on socially significant problems that could be tackled within the school schedule. Moreover, through challenges such as designing a safer shopping cart and elderly mobility aids, Jump discovered that this event could combine the male students' need to race and compete with one another while simultaneously stimulating girls' need for making a societal difference through engineering and design. Indeed, at one point, Jump was able to send a team of four girls and one boy to the National Engineering Design Challenge national championship competition. Soon, he began recruiting exceptional students from those classes.

Jump. I was recruiting my IPS (Introductory to Physical Science) kids. Kids that I knew that were good, and said "hey, if you like this we're going to start a new program next year. Do you want to sign up? So I got 6 kids for the very first semester. We had folding tables and folding chairs and that's all we had… But the first semester was research. All right we are doing these little MIT (Massachusetts Institute of Technology) type projects… So we were just on the computers and looking stuff up and doing research to find out what other types of competitions and what things were out there and it was from that that we found a couple of things to try. FIRST Robotics was the very first thing we did along with something called National Engineering Design Challenge.

Jump. So it was just a meeting of all of this different what I can recall from how I learned, and how I liked to teach, what I saw responding in the kids without any prompting whatsoever. So we just started doing more and more engineering type of competition and got away from all the Quiz Bowl type of things and the buzz in this or just write this test down, truly design work.

There are several approaches used to engage students in engineering concepts in the literature. For example, students may be asked to design a robot to accomplish a specific task only using a certain amount or type of materials. ROBOLAB, which is utilized in the program studied in this report, has been found to be a powerful tool for a range of students studying engineering concepts. The students are provided with a central unit or LEGO "brick" that contains several input and output devices on which they can attach touch, light, temperature, and rotation sensors. The open ended problem posed within this framework, for example, can be to design a bumper car that can be used by a restaurant to serve meals in a limited area (Erwin, Cyr, & Rogers, 2000). The use of unusual materials to construct model artifacts as solutions to

problems, such as building a bridge out of ice cream sticks or spaghetti (ASCE, 2003), or using concrete to construct a boat (Johnson, 1999) have also been used as scenarios to encourage creativity in problem solving. Also, rather than suggesting unusual materials, atypical parameters have be used to create authentic open ended problems. For example, at the University of Liverpool, students were asked to design a house to reflect a piece of music (University of Liverpool, 2003). Lewis (2004) suggested that an advantage to this activity was its ability to force students to engage different senses in a creative way.

Jump. We were looking at individual type projects, we were looking at team type projects, which ones were more study intensive, which ones were more interactive? We in that first year, again we tried Science Olympiad, Science Bowl, we tried some science fair stuff and then we tried FIRST Robotics because that was something fairly new and you got to build these big robots... We tried the National Engineering Design Challenge and I was really focusing on the ones that made them design and build, because this grew out of the freshman physical science when I had them doing design and build projects. They had to design it, they had to understand the laws, simple machines, Newton's Laws in order to design appropriately.

As mentioned, because of this drive to engage students in science through competitions, Jump was initially going to pursue all branches of science because of the variety and availability of such events as Science Bowl, Science Olympiad, Science Fairs, FIRST Robotics, and the National Engineering Design Challenge. Since these contests were taking place in a physical science class at the time, Jump explains that his motivation was to locate events that encouraged students to "design and build."

Jump. I was really focusing on the ones (contests) that made them design and build, because this grew out of freshman physical science when I had them doing design and build projects. They had to design it, they had to understand Newton's Laws, simple machines, in order to design appropriately."

Theme 2: Project based learning and teaching. Problem solving and Problem Based Learning (PBL), regarded as "…an orientation towards learning that is flexible and open and draws upon the varied skills and resources of faculty and students" (Feletti, 1993, p. 146), have become central themes that run through contemporary education. Specifically, contemporary technology education curricula worldwide have begun to center themselves on the topics of problem solving, design, and construction methods (Rasinen, 2003). The reliance this approach to technology education has on fostering creativity and subsequent creative work is significant. For example, since the late 1990's, an increasing amount of Israeli senior high school students have been preparing problem based final projects in technological areas such as electronics, robotics and computer sciences. Students are required to take matriculation exams relating to these types of final projects that are required of the subjects they study to receive a *Bagrut* certificate. This certificate is viewed as imperative for entry into post secondary education (Barak, 2005). In the same article, Barak discusses recent studies that have revealed that problem based learning contributes to students' creative thinking, problem solving abilities and teamwork in Israeli high schools.

For these same reasons, Jump states that project based learning and teaching were implemented.

Jump. So to me what was just the traditional classroom and the teacher would lecture and write all these diagrams on the board. This is what a lever looks like. Here are the pictures in your text book. Do these problems at the back of the chapter, we will take a test on Friday… You've got to do it… It's not just some two dimensional somewhat abstract concept. How do you really make a lever work? There are other issues with the lever, the fact that oh, what happens if the load is too much and the lever itself breaks? What about the bending that happens with it? What about the fulcrums that didn't slide out and screwed out? How do you actually learn this? You don't learn anything unless you do it.

Jump. When I started I was teaching the freshman science, an introduction into physical science courses and I had all of them. Seven classes a day, I taught every kid that came through physical science... I started looking for ways to be creative and reach those kids and around that same time, back in the late 80's, early 90's, Scientific American Frontiers was a real popular show and they always showed MIT robotics competition at Engineering 1 and Woodie Flowers taught, and I just kind of melded the whole thing together.

Jump. It was important for the kids to have a result… They want to know that when they press the button it does something. So that's when we really started getting into mechanics, again back to the MIT thing. You could show that video tape and the boys and girls thumbs are going, whoa that's cool – things moving and doing stuff; empowering students to be able to create something that does the same thing. The problem solving and the creativity it's like art projects… How do I take ownership of my intellect, my creativity? As soon as you do that, that's why we have the numbers that we have.

Jump began negotiation with the school administration for a single period within the school day in order to experiment with a science based course with a hands-on, problem solving focus. In the beginning, projects consisted of mouse trap cars, Rube Goldberg machines, and other science projects used to reinforce concepts that involved simple machines, data collection, analysis, optimization, design, predictive analysis, as well as the process of trial and error.

Jump. The vision of this program is how do I get the people ready to do that creative engineering? Now they could easily take that same mental structure and be an artist, be a business person, because now how to find more creative ways to manage money? More creative ways to make processes cost less, but be more effective.

Theme #3: Emphasis on creative thought and work. This notion of "creative engineering" is well founded in technology and engineering literature. Because of the growth of global networks and their influence on creating an international marketplace, engineering work has less to do with making goods and is concerned more with control of automation and information (Ihsen, Isenhardt, & Sánchez, 1998). The need for structures to withstand harsher environments, be built to greater heights, with greater controllability, and be of greater economy and safety, signals the demand for creativity in engineering practices (Teng, Song, & Yuan, 2004). It has

been said that pressure on engineering educators is to develop ways to foster creativity in engineering students in order to answer the demands of contemporary society and industry that are impacting the engineering profession worldwide (Mitchell, 1998). In the last two decades, engineering education has indeed focused on enhancing students' creativity to meet these various needs (Cropley and Cropley, 2000). This change has necessitated a shift away from traditional engineering curriculums focused on the basic sciences such as physics, math, and mechanics. Industry now requires engineers to possess problem solving ability (Grimson, 2002). When students become engineers, many find projects out in the work place to be fragmented and the flow of information chaotic (Chan, Yeung, and Tan, 2004). This may be due to the fact that many engineering students have the preconception that engineering should be intellectual in nature and involve only deductive reasoning. Because of this approach, students are severely restricted in their thinking when presented with open ended design problems that require creative thought (Court, 1998).

Having said this, one of the most common approaches to training engineering students is presenting them with complex, open ended design problems, much like what Jump discovered in the competitions he employed. These types of problems are designed to represent "real" scenarios or issues and have many possible solutions (Lewis, 2004).

As stated earlier, many of the new design-focused curricula (such as Project ProBase, Principles of Engineering; Project Lead the Way, Principles of Technology; Engineering Technology; Introduction to Engineering; The Infinity Project, Learning By Design, Models and Designs, and A World in Motion) are indeed focused on open ended engineering design problems that yield an end product as a solution. Jump explained that the product produced by such a process has proven to be a very powerful motivational tool.

Jump. So the energy, the emotional, the intellectual, the cognitive engagement in trying to understand something was so different when we were doing these engineering type projects. Just observing that, that's how like I said when we started it with Advanced Competitive Science it wasn't engineering. But seeing engineering hooked the kids. Part of it was the novelty.

Jump. The problem solving and the creativity it's like art projects… kids get very attached to their art work. Even if it's no good you're trying to explain to them why it's no good. They get upset because they take ownership of that art work. That came out of them and they poured that out on the canvas and that was the key to me, it was that ownership. How do I take ownership of my intellect, my creativity? As soon as you do that, that's why we have the numbers that we have… To me Engineering is that creative… it's the desire to wonder what can I make next? How can I get to the next level, what can I invent… how do I look at the world around me and make whatever it is better?

Jump. So that creative, artistic, how do I make it neat and fun and different, but still also know all the math and science and the technology to make it work. Why here is the challenge of the 21st Century at least from my end, if we are going to maintain our edge in the U.S. of being the place everybody comes for the unique new solution, not just the place that reproduces it cheaper, well how do we train the brains to be ready to that? So that's a bit part of how this program has really been built. The vision of this program is how do I get the people ready to do that creative engineering?

As mentioned previously, Jump holds art certification from the University of Dallas and attributes his appreciation of for innovation borne of creative thinking to his training and experiences during his time in the program there. Specifically, he recalls that the environment was as responsible for creative work as was the nature of the tasks themselves.
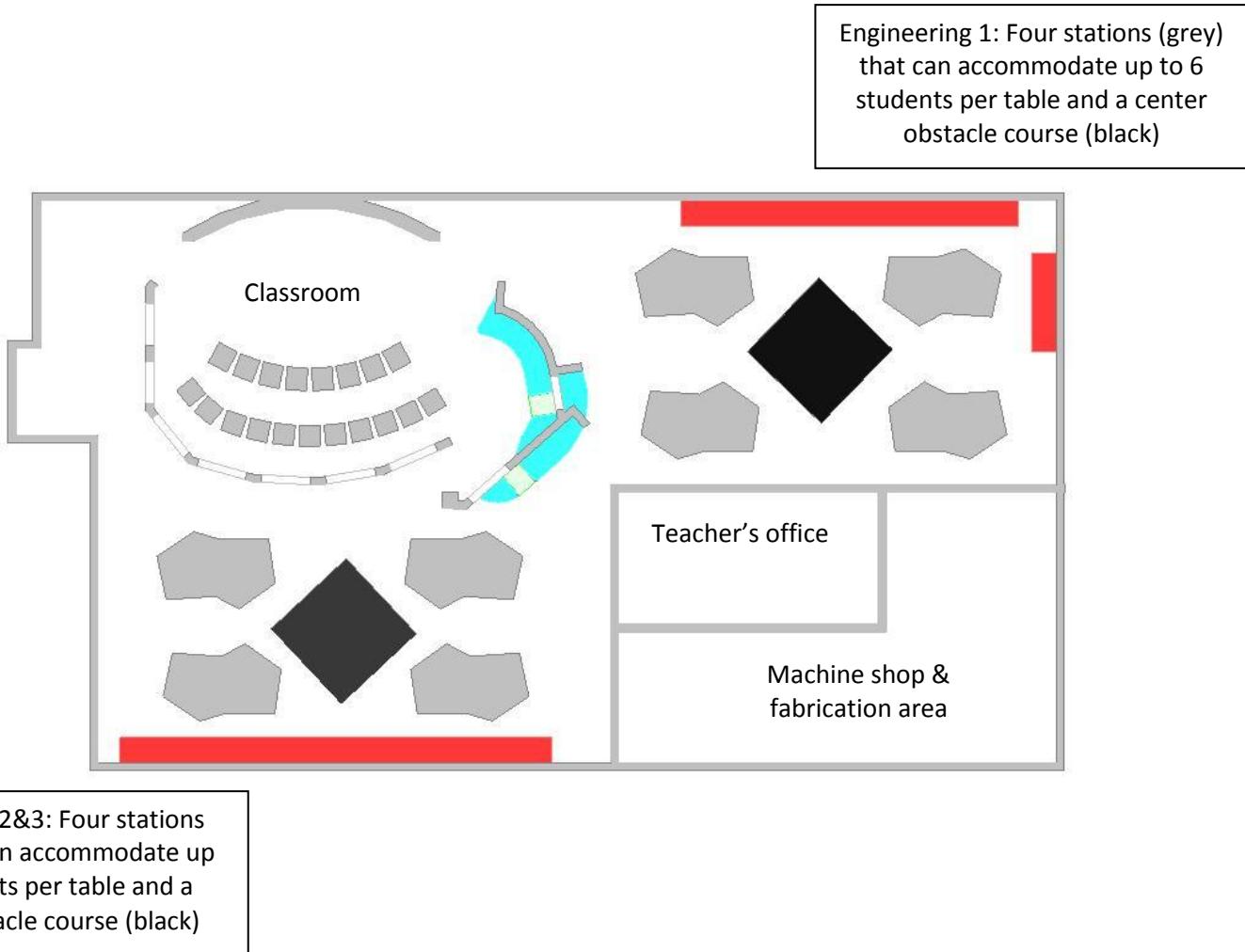
Jump. I worked not only in the science fields but in the art fields, what I saw had more energy were the art working environments. But because in art, especially in commercial art… everybody is… pulling stunts on each other and they are interactive… You have to make it alive. So the environments where I saw it was alive led to better learning. It led to exchange between people. People sharing and looking at different stuff. Oh, what are you doing? Oh how do you do that? Oh mine's better than yours. Now you get some of that playing off of each other. So to me that's the way just a classroom has to be.

Kersting (2003) acknowledged that there are possible similarities and differences in creativity as it related to people in the sciences and artist: "Science has to be constrained to scientific process, but there is a lot less constraint on artists. Many artists come from more chaotic environments, which prepares them to create with less structure" (p. 40). Larson, Thomas, and Leviness (1999) commented that although the opportunity may exist for creativity to exist in both the arts and sciences, there is a possibility that creativity in engineering might be different from creativity in the arts: "A distinguishing feature is that the engineer has an eye on function and utility. Therefore, there may be a creative engineer versus a creative sculptor, painter, poet or musician" (p. 2).

Regarding the classroom environment itself, Amabile (1983) stated that when all the social and environmental factors that might influence creativity are considered, most can be found in the classroom. She categorized environmental factors into areas that included peer influence, teacher characteristics and behavior, and the physical classroom environment. Grouping of students in heterogeneous groups; having a teacher who is intrinsically motivated and believes in student autonomy and self directed work; and being in a cue-rich and therefore cognitively stimulating classroom were all examples of environmental factors influencing student creativity.

Although a variety of environmental variables have been identified that may influence creativity, *climate* is also an important consideration in the discussion (Hunter, Bedell, & Mumford, 2007). At the individual level, climate represents a cognitive interpretation of a situation and has been labeled *psychological climate* (PC) (James, James, & Ashe, 1990). PC theory supposes that individuals respond to cognitive representations of environments rather than to the actual environments (James & Sells, 1981). In essence, the climate of a classroom is a more global view of environmental influences on creativity. Most of the classroom research has focused on the distinction between "open" and traditional classrooms climates (Amabile, 1983, p. 205). *Openness,* not unlike what Jump is describing above, is most often considered a style of teaching that involves flexibility of space, student selected activities, richness of learning materials, combining of curriculum areas, and more individual or small-group than large-group instruction (Horwitz, 1979). In contrast, traditional classrooms consist of examinations, grading, an authoritative teacher, large group instruction, and a carefully prepared curriculum that is carried out with little variation (Ramey & Piper, 1974). As might be anticipated, most evidence

regarding creativity favors open classrooms (Amabile, 1983). A drawing of the ACS classroom and labs can be found below in Figure 1

Engineering 1: Four stations (grey) that can accommodate up to 6 students per table and a center obstacle course (black)

Classroom

Teacher's office

Machine shop & fabrication area

Engineering 2&3: Four stations (grey) that can accommodate up to 6 students per table and a center obstacle course (black)

Jump describes how students take advantage of the energy the environment allows.

Jump. If you look at our lab we have an Engineering I lab and Engineering II and III lab and they are connected. They are open to each other. The Engineering II and III kids, the advanced kids, will go and pick on that at the same time will teach the young kids. Oh you did that, that's not going to work. The young kids will go over to the advanced side and see what they are doing and get inspired. Here's what's coming. So the open environment makes it very much a family, a team and not we're just in this classroom and just this one thing.

Theme 4: Teacher serves as a guide rather than the "sage". Carroll (2000) commented that "the distinctions between 'teacher' and 'student' no longer serves us well. That is why I believe education is rapidly moving toward new learning environments that will have no teachers or students—just learners with different levels and areas of expertise collaboratively constructing new knowledge" (p. 126). Altan and Trombly (2001) offer learner-centeredness as a model for

managing classroom challenges because of its capability of addressing diverse needs of students. Specifically, learner-centered classrooms, as the name implies, place students at the center of classroom organization and respect their learning needs, strategies, and styles. Carroll explains that some moving toward this new learning environment have tried to replace the linear teaching model where the teacher disseminates knowledge ("sage on the stage") with an environment where the students are learning from each other as they focus on a problem set up by the teacher who acts as a "guide on the side". However, Carroll explains that this model is problematic because it places the teacher outside of the learning process. Rather, he suggests that the teacher acts as more of an "expert learner" among the students: "… the expert learner, the more senior, experienced learner, the person we pay to continue to structure these learning activities… is also constantly learning more and modeling the learning process, as opposed to the teaching process" (p.127).

Jump explains his approach to instruction.

Jump. Most of it (instruction) is individualized because in some ways the course really meets that challenge of how to individualize education for a bunch of different kids and what are the different speeds and different ways because as partners they are focused on the project. Some kids are taking off and able to read it and get it on their own and doing lots of things and need little help. Other kids are struggling and they need help with the math…

Jump. … my top level goal, what's the thing that hopefully the kids, at some point can actually explain, but a lot of times they don't even realize it's happening, how they've grown from a kid… waiting for the teacher to give them something to an innovative entrepreneurial researcher.

Jump. For this class what we expect them to do is more like a job, when you come in you punch in and go to work… the first couple of days of the year obviously we're talking to them, introducing them to the program. These are your expectations. These are the things we have to do. But they will walk in and they will see us teachers working with one group of students, the bell will ring or maybe some students stayed later in their free period, while other students come in, get their stuff out and they are working and we haven't said boo, hi, anything to them. They know that they have a responsibility to come in and get to work. Because then in the middle of a project and they know what the project goals are, there are the modules leading them through the different learning concepts. They have the larger targets, so they come and go to work.

Jump. So it's that change (in students)… 'you mean I have to gain some responsibility here, I've got to come in and get to work so I can learn this stuff… not wait on somebody to just hand it to me.' So there is a transition. There are a lot of behavioral things going on with the engineering kits that can be considered soft skills. But a really interesting thing is how we have to counsel them a lot at the beginning. You're behind schedule. Look you've got this many things to do which are worth this many points and each one of them takes roughly 10 hours… So if you break these 18 modules into 10 hours apiece, that's 180 hours. You spend 45 minutes of class, guess what, that's already like a whole year and you're screwing off. You are not going to get done. They don't think that way. They are just used to the teacher taking them day to day and however far the teacher gets it's how far they get.

Research Objective #3

Identify challenges and constraints that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts.

Theme 1: Assessment of student learning. Assessment of student learning is not only desired by educators in order to determine if their students have gained the knowledge they meant to impart, but it is often mandated by government (i.e. No Child Left Behind). However, Kimbell (1997) wrote "the assumption that it is possible to use small, clear discriminators as a means for assessment in design and technology is a snare and a delusion" (p. 37).

Historically, technology educators have chosen the creation of products or artifacts as a means to teach technological concepts (Knoll, 1997). Much of the new engineering design-focused curricula, including the curriculum used in the ACS program, is focused on open ended engineering design problems that yield an end product as a solution. Often this product is meant to embody the learning process students progressed through and, as a result, is used by teachers to assess the learning and creative work that has hopefully taken place. In essence, as Michael (2001) stated, it is this creative product that personifies the very essence of technology. The characteristics of technical problems and the engineering design process often employed to illustrate the steps engineers and designers use to solve technical problems can provide a scaffolding for students to document their work. This scaffolding allows students to concentrate on developing their own ideas, much like in Jump's classes, not in isolation but as part of a class culture. Said differently, neither a product nor a standardized test can always communicate the creative work involved in long-term tasks and multistage projects inherent in modern engineering oriented education. Notman (2000) suggested that use of a portfolio assessment at the high school level, when combined with student-led conferencing, provided his students "with a high degree of ownership and control [that], in turn, [had] a positive effect on their learning, motivation, and behavior" (p. 2). Wiggins & McTighe (1998) in their book *Understanding by Design* also offer guidelines for assessment:

- Feature a setting that is either real or simulated and involves constraints, background noise, incentives, and opportunities an adult would encounter in the same situation.
- Require the student to address an audience.
- Are based on a specific purpose that relates to the audience.
- The student should have an opportunity to personalize the task.
- Tasks, criteria, and standards are known in advance and guide the student's work.

Although he is about to complete a comprehensive curriculum he has developed for his Engineering 1 course that includes written and performance exams at regular intervals, Jump explained that assessment of student learning in the ACS environment has been and, at the Engineering 2 and 3 levels, continues to be challenging.

Jump. So trying to figure out how to measure this was not easy. So the first thing that we had was just basically, well a lot of times we'd go, we're just going to try this. It may work, we may throw it out, we might keep it… So the experimentation aspect of it was a lot of just trying to figure things out and how do you grade a kid when you don't know whether or not the tool you're using is effective at all. The kids may not be able to get any success with it. Just to later find out oh, that sensor doesn't match with that. We've got a sensor that is reading on amperage and not on voltage and we've got it plugged into something that is looking for voltage and no

amperage. So you never got it to work but you worked on it for 6 weeks and then we finally found out it was an electronic thing. Well you can't discount the kids for that. So a big part at the beginning of this program it was like, as long as you come in and you work hard for me and you help us figure this out, I'm going to grade you just like an employee…

Jump. Yes you can measure the learning outcomes if you know how to recognize them. What if you don't know how to recognize them?

Jump. there has been a huge element of experimentation to really understand what can the kids learn, what's good in terms of documentation?... my goal is for you to be able to independently assess different products, different language forms, different micro controllers and make good selections, because at the high end that's what you have to do… that's very different then "here's the kit, just plug it all together."

Theme 2: Stakeholders unease with new pedegogy. As Wagner (2001) observed, teachers are like craftspeople. The profession "attracts people who enjoy working alone and take great pride in developing a degree of expertise and perfecting 'handcrafted products'" such as lessons, activities, and assessments.

> The educational 'fads of the month' that have swept through schools for the past 30 years have served to reinforce the belief of many teachers that innovations are the fleeting fancy of leaders who are here today and gone tomorrow — and so are not to be believed (Wagner, 2001, p. 378).

Wagner mentions that "most educators are risk-averse by temperament.... Most people have entered the teaching profession because it promises a high degree of order, security, and stability" (2001, 378). Change unfortunately requires disagreement, conflict, anxiety, etc. Evans (2000) adds that "In schools… conflict avoidance is a way of life. Teachers are, after all, people who thrive in — and often prefer — the company of children and adolescents and who try to accentuate the positive. Would we want our children taught by people who *didn't*?" (2000).

Fellow teachers as well as parents expressed concern for the approach the ACS program took to teaching science.

Jump. Some of them (teachers) are a little older. Some of them, especially if you are the new teacher… are looking at you going "what are you doing, that's not the way we do things."

Jump. When I first started teaching IPS this way, oh there were parent phone calls, what's he's doing, how come we're not doing this traditional process… My kids have to take the SAT and get into college and how is this helping them do that? It's not the traditional classroom. The fact that when I went to school we sat in those rows and we answered those questions out of the textbook and he doesn't send any homework home and his tests are all goofy and it doesn't look anything like what real school looks like. So that was one of the things that my administrators dealt with. They filtered it. I didn't find out a lot of these issues until later when they would talk about "you would not believe how many phone calls we got when you first started doing this kind of stuff."

Research Objective #4

Strategies used to overcome challenges and constraints that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts.

Theme #1: Financial and instructional support through business partnership. It has been established that there is a growing need for engineers in the U. S. (Clayton, 2005). Indeed, industry and business have more positions available for engineers than there are graduates emerging from universities. The increased number of graduates in engineering in China and India add to concern about the lack of budding engineers in the U. S. (Dugger, 2009). Additionally, industry now requires engineers to possess problem solving ability (Grimson, 2002). It has been reported that when students do become engineers, many find projects out in the work place to be fragmented and the flow of information chaotic (Chan, Yeung, & Tan, 2004). This may be due to the fact that many engineering students have the preconception that engineering should be intellectual in nature and involve only deductive reasoning. Because of this approach, students are severely restricted in their thinking when presented with open ended design problems that require creative thought (Court, 1998). Indeed, Chan, et al. (2004) found that a newly hired engineer, educated under the traditional engineering curricular paradigm focused on the basic sciences such as physics, math, and mechanics, can take as much as six to twelve months to become professionally competent.

Not surprisingly, the engineering community, including engineering professional societies, schools of engineering, and firms that depend heavily on engineering talent, have spent hundreds of millions of dollars annually on initiatives to raise the level of the public understanding of engineering (NAE, 2002). It is not hard to understand why businesses would desire to be involved the proper preparation the future workforce. Regarding engineering education specifically, the benefits to businesses requiring novel thinking and technical savvy of their future employees is clear. NAE (2009) outlines the potential benefits to students of including engineering education in K–12 schools can be grouped into five areas:

- improved learning and achievement in science and mathematics;
- increased awareness of engineering and the work of engineers;
- understanding of and the ability to engage in engineering design;
- interest in pursuing engineering as a career; and
- increased technological literacy (pp 49-50).

Benilde-St. Margaret's is a private Catholic school that relies heavily on donor support. Termed "Friends of Benilde-St. Margaret's," these private donations can and are often made by local businesses. However, when Jump began the ACS program, his intention was not to campaign for specific funding. Rather, funding came to his program, or more accurately, his appraoch to teaching engineering during a chance encounter.

Jump. Being a private school you have donors... So I think it was one of those come on over, let's show you the cool things we're doing and get you to write us a check type of visit. So again it was just a very informal thing, from my end, it was just oh people walked through the door, oh hi, how are you doing Mister So and So, nice to meet you. I had no idea they were coming.

One donor in particular was the CEO of a local engineering firm. Jump explained that he was intrigued not only by the approach the new ACS program took regarding the teaching of science and engineering concepts, but the degree to which it addressed his concerns about the lack of local talent.

Jump. [the donor] really liked it and that's when this program started, because he challenged us. He said, "Can you do more with this type of program, this type of learning?" Back in the late 90's he already saw the need as someone that owned an engineering firm that we got to get more kids into engineering because all of our talent is starting to leave. Whereas before they would come here from China and India and stay here, now they are starting to get recruited back.

The financial support this particular donor offered allowed Jump his ACS students the freedom to proceed in a way that was uninhibited by administrative concerns about program costs.

Jump. …the first obstacle is always financially how do you build something like this and/or what is it you're building? You go to the administration and say "well I want to do this thing and they're going to want to know what's going to look like and what's it going to cost? We didn't have to worry about that because one of our donors gave us a challenge grant and said, Can you build something? So I didn't have to politic and try and talk my administrators into doing this.

However, Jump explains that although financial freedom is important, the technical support and guidance offered by the donor was just as valuable.

Jump. We're building big robots… we don't know what we are doing and we partner with [company name] Engineering and they are doing some design and working with the kids and we even created Engineering Fridays where those kids that only attended my class on Fridays that spring semester. So they would go to normal classes Monday through Thursday and then Friday we all spent the whole day over in the warehouse at Banner which is where we were building this, as I still only had a folding table and 6 chairs. I had no equipment, no tools, nothing.

Jump. [company name] Engineering were a big help… it would have been impossible without a machine shop and tools and all that, because we had no tools. I didn't even have a screwdriver.

Jump. The CEO of [company name] Engineering… I would just call over to him, 'these were our ideas' [he would say]… 'all right we will set it up. I will get together with the machine shop guys and we will make this happen. We will try it out.' So he was excited about letting us experiment and supporting our experimentation.

Theme #2: Administrative Support. It should not be surprising that support generally leads to confidence and a subsequent feeling of freedom to take chances. Specific to teachers

involved in teaching technology, Wright and Custer (1998) found that along with a lack of understanding and support for technology education, teachers of the discipline indicated a lack of support funding for equipment, supplies, and facilities by administration as the most frustrating aspect of teaching technology education. Relative to support of teachers generally however, Newmann, Rutter, and Smith (1989) found that when school administrators offer teachers help, support, and recognition, they developed a heightened sense of unity and cooperation for the nature of their work. Jump describes that the administration at Benilde St. Margaret's, fueled by the desire to both encourage a potential donor and confidence in his teaching ability, afforded him room to experiment while he developed the ACS program.

Jump. My administrators had a lot of confidence in what I was doing. Because I was teaching all the freshman science courses and I was doing the freshman science courses based on these competitive projects, like what was happening with MIT at the time.

Jump. Let's just try it and see what happens and if it blows up, oh that was cool… when the administrators walk in and go, 'the whole thing just blew up, you just blew up a $600 camera!' I could either get fired or they could say, whatever, keep going.

Jump. [parents said] 'he doesn't send any homework home and his tests are all goofy and it doesn't look anything like what real school looks like.' So that was one of the things that my administrators dealt with. They filtered it. I didn't find out a lot of these issues until later when they would talk about 'you would not believe how many phone calls we got when you first started doing this kind of stuff.'

Findings and Discussion

The purpose of this section is to summarize and then discuss the findings of this case study. Specifically, each finding will be accompanied by a discussion of the effect on high school engineering education. In review, the objectives of the study were to:

(a) describe high school engineering curriculum developed with the sole purpose of delivering math and science literacy;

(b) identify teaching strategies used at the high school level in the process of delivering math and science literacy in the context of an engineering program;

(c) identify challenges and constraints that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts; and

(d) strategies used to overcome these obstacles.

Finding #1: Teachers desiring to deliver engineering ideas via a naturalistically developed curriculum need to have firm conceptual understanding of the content they aspire to deliver. Throughout the interviews the researcher attempted to ask on several occasions what particular skills he and the ACS curriculum were able to deliver. When pressed, the teacher alluded to a CAD program, the ability to use certain automated tools to make custom parts for robots, and being able to manipulate LEGO pieces to achieve a certain task demanded of the modules he had authored. However, these references were few. Rather, Jump spoke often of the desire to have students understand not only specific concepts such as force, statics and dynamics, simple machines, torsion, cross bracing, material properties, programming, and electronics, but

broad ideas such as problem solving, research, analysis, and design. At one point, the researcher asked why he didn't spend more time teaching his students how to use the extensive machine tools in his classroom. He explained simply that they were all very unsafe, but more importantly, Jump indicated that this wasn't his goal. He needed to focus on what he felt was important that students learn in the short time he had with them:

> It's like my goal is not to teach them how to be a machinist. My goal is to teach them how to problem solve… To me [machining is] a job specific skill. If I need to learn how to use this machinery for my job, I can learn it at the job, sort of that apprenticeship type of thing. I don't need that in high school… how much time do I have? I can't teach them everything.

Disturbingly, in *Technology for All Americans* (International Technology Education Association, 1996), the fact that a rationale and structure for the study of technology is presented is evidence that the issue of an agreed upon conceptual structure still remains unclear. However, since concepts such as design, engineering design, trouble shooting, and problem solving appear frequently in standards more recently written for technology educators (International Technology Education Association, 2000), it seems evident that not only is the fog is being lifted, but concepts related to engineering, much like what is being focused on in ACS program being studied here, are appearing as a common theme. Indeed, it could be assumed that as these concepts are more clearly defined or at least universally agreed upon, a concerted effort by teachers to explore novel ways of delivering these ideas can begin en masse. However, this type of curricular exploration, discovery, and development demands an open mind, a degree of ease with the unknown, and support. These traits will be outlined in the following findings.

Finding 2: Teachers wanting to develop an engineering program need to "think big". As it was noted, the ACS program used available science and engineering competitions as a backdrop for activities designed to teach physical science and engineering design concepts. This approach is not in itself novel. Super mileage vehicle competitions (Thompson & Fitzgerald, 2006), the West Point Bridge Design Contest, FIRST Robotics Competition, FIRST LEGO League, and the Science Olympiad (Wanket, 2007) are all team based competitive activities that are frequently mentioned in engineering and technology education literature for their ability to encourage students to work together to solve problems with specific technical parameters. Unique to Jump's approach was a focus on competitions not only happening at universities that were considered "high church" relative to engineering education such as the Massachusetts Institute of Technology (MIT), but what was being publicized by the media through programs such as Scientific American Frontiers on the Public Broadcasting Service (PBS). He commented that in addition to adding to his own excitement about the content, these entities added a degree of importance and legitimacy to the work students were doing and his approach to the material. Beside setting the bar high by using exemplary university level activities to provide the basis for instruction, in order to help him guide his pedagogy Jump leveraged engineering related reference materials published by the faculty at these institutions such as *Designing Engineers* by Louis L. Bucciarelli (1994) of MIT and *To Engineer Is Human: The Role of Failure in Successful Design* by Henry Petroski (1985) of Duke University. He commented that these were

types of books that were tremendous resources in forming the platform for his naturalistic approach to developing the ACS curriculum:

> …all these books came about in my exploration once we started this program. What is advanced competitive science? What is it that we are trying to do? Again we didn't do top down. I didn't start off with a set of objectives and we're going to meet those objectives.

Students who had graduated from Benilde St. Margaret's and the ACS program and progressed to engineering programs were also rich sources of input to the program. This information helped Jump maintain a curriculum that was consistent, relevant, and contemporary. Said differently, he wanted to prepare students for what they would find in college:

> Then as the kids were graduating getting feedback from the colleges, 'Oh this was great, I knew this and none of the other kids did' or 'you know we did that but that didn't help me at all.' So just allowing the feedback from the kids, what's working, what's not, then we can tweak the program and start really understanding what the colleges are looking for. What are the critical skill sets when the kids are going into engineering school that pay huge dividends for them versus the things that just weren't working that way?

Jump also discovered through developing his ACS curriculum that he had a tendency, shaped by years of being a teacher accustomed to tight program budgets, to let the high cost of entering certain competitions or buying contemporary technology for the program hold its true potential back. Because of the attention his approach to science and engineering garnered from local industry, financing became, in essence, a non-factor. Even so, he explained it was hard for him to grow accustomed to spending money:

> So [a private donor] was excited about letting us experiment and supporting our experimentation. You know, gave me a credit card… like a $10,000 limit… I'm like what?!... It was like what's my budget, how much can I spend? [the donor said] don't worry about it, just get what you need… I come from a background where we've got $500 for the whole science department, what do you mean…just get what you need? This one thing cost $400. I couldn't do that… do you mean, just spend, $10,000 I had no concept of how to spend this.

Finding 3: Teachers desiring to naturalistically create an engineering curriculum need to be at ease with the creative process and the ambiguity involved in learning new content and contemporary technology. It was evident through interviews and observations that Jump was at ease with a certain degree of vagueness and uncertainty. The researcher often recorded him either saying to students or referencing instances that, because he didn't know the answer, resulted in a response of or related closely to, "I don't know. Let's find out."

Guilford (1950), a pioneer in the study of creative personality, identified an ability to evaluate, deal with complexity, reorganize, change one's mental set, possess sensitivity to problems, and the capacity to produce many ideas as salient features of creative personalities. Although he was diligent in his pursuit of building the ASC program on novel ways of approaching science and engineering concepts, Jump repeatedly mentioned that the process was fraught with curricular, pedagogical, and technical trial and error. It was obvious that he was able to take this in stride rather than view it as a set back or a case of "loosing face" in front of

students. Related literature would suggest otherwise. It has been found that a teacher attempting to make such a curricular shift, like that required for successful implementation of engineering design activities offered in the ACS program, may feel uncomfortable because what they are being asked to teach is not reflected in their own educational experience (Anderson & Roth, 1989; Ball, 1996). As opposed to the disposition Jump displayed in this research, some teachers may view themselves as only source of knowledge in the classroom. This can have serious implications in an environment that obviously demands flexibility and an ability to deal with novel problems that can arise (Ogle & Byers, 2000).

Finding 4: Administrative support for program development relies as much on the teacher's record of solid instruction and demonstrated student learning as upon available financing. Although Jump displayed the demeanor of a teacher who portrayed intellectual and managerial suppleness, he had established a history of success in student learning demonstrated through standardized assessment. Since Benilde St. Margaret's is a private college preparatory school, it is imperative that its students are at least able to perform well on the entrance exams whose chief concern is measuring competence in core subject areas, not the least of which include math and science. It is important to mention that there is no tenure for teachers at Benilde. This could certainly be interpreted as a motivating force to apply to teachers to be held accountable for student learning. Jump clearly explains, "There is no tenure at this school… I could get fired today just like anybody else for lack of job performance. No tenure. No union… it's all job performance."

Additionally, Jump's ACS program is an elective and does not apply as a science or math credit needed for graduation. Therefore, the obvious pressure to support the college preparatory ethos of the school and the population the ACS program serves is palpable. The program has produced results. Jump explained.

> I think the proof started coming in with these kids as they moved through, were doing better in their physics classes, better in their math classes, because that was something we started to get a reverberation of. Their grades would come up. Now I got that through parent/teacher conferences… So the administrators liked what I was doing and saw that the benefit and were getting a lot of positive feedback from the parents.

It has been suggested that if teachers are to be successful when venturing into new realms such as the ACS program, they must have both strong pedagogical and content knowledge to remain comfortable in their classrooms (Tobin & Fraser, 1990). It would appear that the degree to which the teacher understands the school's core curricular aims and can deliver engineering content that is in alignment with and sensitive to those aims would influence the success of such a program.

Conclusions

The initial research objectives were to: (a) describe high school engineering curriculum developed with the sole purpose of delivering math and science literacy; (b) identify teaching strategies used at the high school level in the process of delivering math and science literacy in the context of an engineering program; (c) identify challenges and constraints that occur during the delivery of high school engineering curriculum designed chiefly to deliver math and science concepts; and (d) strategies used to overcome these obstacles.

In addressing the first research objective, teachers interested in creating and delivering deliver engineering naturalistically need to begin the process with clear thinking relative to a

conceptual framework they would deliver to students. The characteristics of open-ended problems, which are being suggested as the richest way to deliver such a curriculum, defy attempts to assemble reliable list of skills needed. This is not to suggest that valuable skills will not be developed along the way to assembling novel solutions to real world scenarios suggested. Rather, as opposed to a curriculum that attempts to develop students' understanding of all engineering concepts, pains should be taken to focus on a thorough treatment of a particular concept. By teaching through this lens and allowing time for students to wrestle with the iterative nature of open-ended problems, deeper, more meaningful and transparent understandings can occur.

Teaching strategies rely on the teacher's comfort with their ability to adapt to ambiguity and novel situations that occur within open-ended problem solving that are characteristic of effective engineering curricula. Support and validation for such an approach can be gained by utilizing activities and challenges offered by the institutions and organizations that represent the best thinking in the field. Additionally, reference materials should be compiled from these same sources to act as a daily reference for engineering teachers. It is important to note that these resources may vary in accordance with the learning style and prior knowledge of each individual.

Obstacles to successfully developing and implementing a naturalistically developed engineering curriculum can be addressed by establishing administrative support and gaining business and industry instructional and financial support. Administrative support can be established by a teacher's record of student learning relative to the school curricula. This can be accomplished by a teacher's pointed efforts to first offer a curriculum that features powerful learning activities that are underpinned by the teacher's articulated understanding of the concepts they were built to teach. Next, involvement of local business and industry in department and school advisory committee functions, school and district open houses, volunteer, and guest speaker opportunities not only demonstrate a teacher's vision extends outside the school building, but allows for potential supporters to see and experience the energy that often characterizes engineering work.

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Appendix A

Consent to Participate In UW-Stout Approved Research

> This project has been reviewed by the UW-Stout IRB as required by the Code of Federal Regulations Title 45 Part 46

Title: A Case Study of Teaching Engineering Concepts in Science

Investigator:
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Description:
When many of the engineering curricula is designed to be infused in an existing technology education program, how do high school engineering education programs derived organically from a science and math emphasis approach engineering design curriculum? In essence, can there be a distinction made between different "learning environments" in the sense of intellectual outcomes targeted (technological literacy vs. science and math literacy) by the subject being taught?

In an attempt to answer these questions, I will conduct interviews with you at your school, Benilde-St. Margaret's in St. Louis Park, MN, make classroom observations, and examine curriculum documents, lesson plans, and journals. I will conduct a pre-interview to ask what you considers is relevant data to collect in order to capture the experiences. The following questions will be used to guide the interviews but questions may be adopted upon completion of the pre-interview or during the interview process.

1. Why have you chosen to implement engineering into a high school science program?
2. What changes have you had to make to your science curriculum to teach engineering concepts?
3. What new strategies have been generated in order to successfully implement engineering curriculum?
4. What curriculum resources have been most helpful to you in order to make this change?
5. What equipment, tools, and software have been added to your classroom for the purpose of effectively delivering engineering concepts?
6. What challenges or constraints have you faced when seeking to implement engineering concepts into your classroom?
8. How have you overcome those identified challenges/constraints?
9. What advice would you give a technology teacher who seeks to implement an engineering course?

Risks and Benefits:
You might feel some discomfort during classroom observations and interview sessions.

Data collected during this study could be used to investigate delivery methods that successfully deliver engineering concepts in classrooms. By this increased understanding of how to effectively develop, teach, and evaluate engineering curriculum at the high school level, the information you provide could inform area teachers how to choose and implement engineering curriculum based on the needs of their students, department, and school district.

Time Commitment:
You will be asked to participate in five one hour interviews. In addition, a pre interview will be conducted of the same length before data collection begins. Four phone call and/or email follow up communications will also be conducted to verify the data.

Confidentiality:
All data will be collected and stored on a non-networked server hard-drive that will protected via passwork. This password will only be accessable to the researcher.

Right to Withdraw:
Your participation in this study is entirely voluntary. You may choose not to participate without any adverse consequences to you. Should you choose to participate and later wish to withdraw from the study, you may discontinue your participation at this time without incurring adverse consequences.

IRB Approval:
This study has been reviewed and approved by The University of Wisconsin-Stout's Institutional Review Board (IRB). The IRB has determined that this study meets the ethical obligations required by federal law and University policies. If you have questions or concerns regarding this study please contact the Investigator or Advisor. If you have any questions, concerns, or reports regarding your rights as a research subject, please contact the IRB Administrator.

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Statement of Consent:

This section should include the language, "By signing this consent form you agree to participate in the project entitled, *(*A Case Study of Teaching Engineering in Science*)*."

_____

Signature.. Date

Appendix B

Module 1 – Building with LEGO® Structural Elements: LEGO® Dimensional Mathematical Relationships and Stable LEGO® Structures

    1.1 Introduction to LEGO® Element Design

        1.1.1 LEGO® Element Basics: The FLU

        1.1.2 LEGO® Element Evaluation 1.0

        1.1.3 LEGO® Element Evaluation 2.0

    1.2 Introduction to LEGO® Structures

        1.2.1 LEGO® Element Integration: Woes of Friction

        1.2.2 Cross Them Up

        1.2.3 LEGO® Element Dimensional Mathematical Relationships: Basics

        1.2.4 Cross Them Up: Evaluation 1.0

        1.2.5 LEGO® Element Dimensional Mathematical Relationships: Structures

        1.2.6 Let's Get Diagonal

        1.2.7 Let's Get Diagonal Evaluation 1.0

        1.2.8 LEGO® Element Dimensional Mathematical Relationships: Diagonals

    1.3 Multi-Plane LEGO® Structures

        1.3.1 Axial Relations

        1.3.2 Axial Relations Defined

Module 2 – Exploration of Fundamental Machine Mobility Issues: Experimentation with Basic Drive and Direction Systems

    2.1 Designing for Mobility: Tracking

        2.1.1 Machine 1A

        2.1.2 Machine 1A: Mobility Issues

        2.1.3 Machine 1A: Loads

        2.1.4 Machine 1A: Alterations

            2.1.4a What is a Caster?

        2.1.5 Mobility Issues: General Observations

Module 3 – Study of Force: Mechanics

    3.1 Introduction to Force

        3.1.1 Reach Out: Preparation 1.0

        3.1.2 Reach Out Evaluation 1.0

        3.1.3 Force Basics: Beginnings

        3.1.4 Reach Out Evaluation 2.0

        3.1.5 Force Basics: Gravity, Weight and Mass

        3.1.6 Reach Out Evaluation 3.0

        3.1.7 Force Basics: Expanded

        3.1.8 Reach Out Evaluation 4.0

        3.1.9 Reach Out: Preparation 2.0

    3.2 Force and Simple Structures

        3.2.1 Simple Structures Explored

        3.2.2 Members, Joints and Trusses

        3.2.3 Reach Out Again with Trusses